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THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
High Altitude Engineering Laboratory
Departments of
Aerospace Engineering
Meteorology and Oceanography

Final Report
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1 March 1963 to 30 June 1969

Introduction

This report summarizes the activities and publications of a research program in upper atmospheric physics undertaken by people in the High Altitude Engineering Laboratory of the University of Michigan. The program has been supported by various contracts, mostly from NASA, for a number of years. The work has emphasized rocket measurements of the structure of the neutral atmosphere. Recently studies in ionospheric physics and airglow have been undertaken and this expansion of interest has been accompanied by an increased proportion of analysis. The program continues under NASA grant NGR 23-005-360.

28 February to 30 June 1969

During the final four months of the contract the principal effort was expended on interpretation of rocket data. In one case a comparison of neutral N_2 was made among three nighttime mass spectrometer flights flown at different latitudes. The results have been published as a scientific report* and have been submitted to the Journal of Geophysical Research. The

*Schaefer, E. J., A Latitude Comparison of N_2 Density Measurements by Mass Spectrometer, Univ. of Michigan Report 03400-1-S, December 1969.

abstract follows:

> Ambient N_2 densities at altitudes between 100 and 200 km derived from the data of three nighttime mass spectrometer rocket flights at different latitudes are compared. The three flights occurred under nearly identical solar and geomagnetic conditions. The temperate and northern N_2 densities are compared with results obtained by other experimenters and found to be in good agreement. A density gradient, increasing with increasing north latitude is a principal result. The southern tropic N_2 density is found to be about 10% of that above Wallops Island at an altitude of 200 km. Satellite data are shown to support the results qualitatively. The possibility that the low tropic density is due in part to instrumental error is considered. It is concluded that the weight of experimental evidence supports the validity of the results. The extremely low temperatures around 110 km which are deduced from the tropic density results are shown to be compatable with mesopause temperatures derived from a grenade experiment at nearly the same latitude.

Another major effort was re-designing the Michigan Airglow Payload (MAP) for recovery. This task was accompanied by work on the various sensor. The six-channel turret photometer was completed and preliminary tests were run using the night sky as a known signal source. The HARP photoelectron differential energy analyzer was tested on the vacuum system and proved to be capable of determining the photoelectron energy spectrum with a resolution of 10, as desired.

Another major task during the interval was adapting the level of activity to a much lower level of funding. Making new organizational arrangements, revising experiments, studies and schedules and finding employment for discharged people occupied much of the time of the principal investigators.

Rocket Launchings During the Contract Interval

Of the forty seven rockets launched by the Laboratory during the interval, twenty one were supported by this contract. Eleven rockets had neutral/ion mass spectrometers as the principal instrument, eight carried falling spheres for neutral density and winds, and two were devoted primarily to airglow intensity and the study of photoelectronic excitation. There were three failures in the group, one "partial" and seventeen successes.

Papers and Letters

Schaefer, E. J. and M. H. Nichols. Neutral composition obtained from a rocket-borne mass spectrometer. Space Research IV, North Holland Publ. Co., Amsterdam, pp 205-234, 1964.

A quadrupole mass spectrometer has been designed for studies of neutral atmospheric composition between 100 and 200 km using Nike-Cajun and Nike-Apache rockets. A successful technique of ejecting the payload at altitude from an evacuated volume to reduce contaminants has been developed. The ion source has been designed for direct immersion in the ambient atmosphere with the greatest open look possible. The number of surface collisions experienced by a particle prior to ionization has thereby been reduced to the order of one or two and the probability of surface recombination of atomic oxygen has been correspondingly reduced to the order of one percent.

The first successful daytime flight of a continuing program yielded an O_1 / O_2 current ratio which was unity at 118 km and 3.1 at 134 km. Preliminary data analysis of the first successful nighttime flight yielded O_1 / O_2 current ratios in substantial agreement with the daytime flight and extended the data to 190 km where the ratio was 9.5. These values are about an order of magnitude greater than those obtained heretofore by other investigators and achieve much closer agreement with ultraviolet measurements, and theoretical predictions.

On the basis of the daytime data, a mean molecular weight of approximately 24.6 is derived at 134.5 km.

Schaefer, E. J. and J. Brown, Additional rocket-borne mass spectrometer measurements of the dissociation of oxygen, J. Geoph. Res. 69, No. 7, pp 1455-1456, 1964 (letter).

Schaefer, E. J. and M. H. Nichols, Upper air netural composition measurements by a mass spectrometer, J. Geoph. Res., 69, No. 21, pp 4649-4660, 1964.

A quadrupole mass spectrometer with an ion source designed to minimize recombination effects was flown on a Nike-Cajun rocket, NASA 10.91 UA, from Wallops Island (latitude 37°50'N, longitude 75°29'W) at 1302 EST, May 18, 1962, to an altitude of 134.5 km. The results indicate a ratio of O/O_2 number densities of 3.1 at apogee with a rms error estimated at 0.3. At apogee, the ratio of N/N_2 number densities was less than 0.05, and the ratio of ion currents due to constituents of mass greater than 40 was less than 0.04 of the total ion current. The mean molecular weight computed from the data at 133 km is 25.5 with a rms error estimated at 0.4. These data are uncorrected for effects of the motion of the instrument package. On the basis of a simplified geometrical model, bounds on the dynamic effects are established.

Ghosh, S. N., Ionospheric characteristics from altitude variations of positive ion densities, Trans. Amer. Geoph. Union 48, No. 1 p 65, 1967. (also Annal d'Geoph., 1968)

Altitude variations of different types of positive ions in the ionosphere obtained from rocket-borne experiments, have supplemented the collective information of ions obtained from ground-based experiments and have given additional information of the ionized layers of the upper atmosphere. Among other conclusions it is shown that, whereas for O^+ and N_2^+, photoionization is important, greater numbers of O_2^+ and NO^+ ions are created by charge exchange of ion-atom interchange reactions from ions originally produced by solar rays. This conclusion is confirmed by the observed low densities of O^+ and N_2^+ ions at night. It is proposed that the conclusion can be settled conclusively by noting the variation of positive ion densities during a flare or at an eclipse.

Analysis of the data shows that at each level between 100 and 280 km the total rate of production of different types of positive ions by solar rays is approximately equal to their total loss rate. Since the lifetimes of ions are small, the steady state is reached within a short time when the divergence term becomes nearly equal to zero.

To understand the overall loss rates of positive ions in the ionosphere, the effective recombination coefficient of positive ions with electrons is defined in line with the effective electron recombination coefficient, and its values for various types of recombinations are given.

Schaefer, E. J., Temperature and composition of the lower thermosphere obtained from mass spectrometer measurements, Space Research VIII, North Holland Publ. Co., Amsterdam pp 959-968, 1968.

A sufficient number of mass spectrometric measurements of upper atmospheric composition have been made to indicate the nature of diurnal and latitude effects on composition and mean molecular weight. Date for three latitudes are described and diurnal changes are illustrated. Measured mean molecular weights above Wallops Island and Fort Churchill, Canada are presented.

Temperatures, computed from the altitude rate of change of the ratios of selected pairs of constituents, are presented and comparisons are made with other measurements and with standard models.

Ghosh, S. N., Distributions and lifetimes of N and NO between 100 and 280 kilometers, J. Geoph. Res., 73, No. 1 pp 309-10, 1968.

The distribution of N atoms between the altitude range 100 and 280 km has been computed from reactions between constituent particles of the atmosphere and assuming their rate coefficients at laboratory temperature. It has been found that the latter distribution, which is considerably different from the former, gives a reasonably good profile. Since, in many cases, reactions involving loss of N atoms lead to the production of NO molecules, the altitude distribution of NO molecules is also calculated. The computed N and NO distributions compare favorably with certain rocket experiments and laboratory data. From the loss processes, the lifetimes of N and NO are computed.

Jones, L. M. and J. W. Peterson, Falling sphere measurements, 30 to 120 km, Meteor. Mon. 9 No. 31, Amer. Meteor. Soc., pp 176-189, 1968.

Various versions of the falling sphere experiment have been used since 1952. Spheres equipped with sensitive accelerometers and passive, radar-tracked, inflated spheres are discussed. Soundings with the latter system are more prevalent and are discussed in some detail. With the best radars, density is measured to 120 km and winds to 70 km. Problems have to do with the effects of vertical wind, anomalous aerodynamic flow and loss of inflation gas. Flight comparisons with grenades, bead thermistors and mass spectrometers are discussed. Results from falling sphere soundings have been used for constructing profiles of model atmospheres, for a tropical survey in all seasons, and for studies of an explosive stratospheric warming, southern hemisphere circulation, the fine thermal structure of the mesopause, and the vertical scale of stratospheric and mesospheric winds.

Schulte, H. F., J. W. Kuiper and E. K. Miller, Ionospheric electron density measurements, Part I: Results from three rf swept frequency techniques, Proc. URSI Meeting, Wash., 1968.

Preliminary results from three rf experiments swept in frequency from 0.9 to 10 mHz are presented. Electron densities derived from impedance measurements are compared with an electron density profile obtained from a ground ionosonde. Also, results of a plasma resonance detector and a rf level probe, including some rather unusual responses are discussed.

Of the three experiments, two utilized a 30 foot tip-to-tip balanced electric dipole which was excited by a balanced oscillator with an output level of approximately 3.7 volts rms. Every two seconds the frequency range was swept alternately from 0.9 to 3.3 mHz and from 2.6 to 10 mHz. One of these experiments measured the absolute magnitude of antenna impedance while the second experiment, new in concept, simultaneously detected local plasma resonances. As a third experiment a small rf probe mounted near the nose cone tip monitored the propagated rf signal level as the main dipole was swept in frequency.

These experiments, two mass spectrometers, and a Langmuir probe were flown to an altitude of 292 kilometers above White sands, New Mexico aboard an Aerobee rocket while the OGO-D satellite overflew that location on 8 August 1967 at 0657 hours, local time.

Schulte, H. F., J. W. Kuiper, and E. K. Miller, Ionospheric electron density measurements, Part II: A comparison of experiment and theory for an antenna in the ionosphere, Proc. URSI meeting, Wash., 1968.

An analysis of a plasma-immersed antenna undertaken in support of an experimental program of ionospheric measurements with particular emphasis on the electron density, is discussed. Some numerical admittance results for an infinite antenna in a compressible magnetoplasma show that the plasma anisotropy and the ion sheath strongly influence the admittance while the plasma compressibility is by comparison, relatively unimportant.

Consequently, the use of a theory for a finite antenna in a magnetoplasma which neglects plasma compressibliity appears to be a reasonable first-order approximation. A comparison of the experimental impedance results presented in Part I of this paper with the impedance predicted by Balmain's (1964) quasistatic theory provides good evidence of this. In particular, the experimental impedance variation with frequency above the upper hybrid frequency (f_t), and an impedance maximum associated with f_t are shown to be in good agreement with Balmain's theory. An impedance minimum which occurs above the electron cyclotron frequency, and the interference pattern observed on a small receiving rf probe as the transmitting antenna is swept in frequency, may both be interpreted to indicate the excitation of an electron acoustic wave.

Ghosh, S N., et al, Atomic nitrogen in the upper atmosphere measured by mass spectrometers, Jour. Geoph. Res., 73, No. 13, pp 4425-6 (letter) 1968.

Miller, E. K., Admittance of an inhomogeneously sheathed infinite cylindrical antenna immersed in an isotropic, compressible plasma, IEEE Transactions on Antennas and Propagation AP-16, No. 4, pp 501-2, 1968.

The admittance of an infinite cylindrical antenna excited at a circumferential gap of nonzero thickness and immersed in a lossy, iostropic compressible plasma medium is obtained from numerical calculations, taking into account the inhomogeneous ion sheath which forms about a body at floating potential in a warm plasma. The admittance for the inhomogeneous sheath is found to be fairly similar to that for the sheathless case, with the exception of a rather sharp maximum or resonance in the admittance just below the plasma frequency which results from the sheath inhomogeneity.

The complete list in this series follows:

Miller, E. K., Admittance dependence of the infinite cylindrical antenna upon exciting gap thickness, Radio Sci., 2, No. 12, 1967.

Miller, E. K., Admittance of the infinite cylindrical antenna in a lossy incompressible, anisotropic plasma, Can. J. Physics, 45, No. 12 pp 4019-4038, 1967.

Miller, E. K., The admittance variation about the plasma frequency of an infinite dipole antenna in an ionospheric type plasma, Proc. URSI Meeting, Ottawa, 1967.

Miller, E. K., Antenna admittance in a compressible magnetoplasma, Plasma Physics Meeting, Univ. of Texas, 1967.

Miller, E. K., Electromagnetic wave scattering from a cylinder immersed in a warm plasma, Radio Sci., 2, No. 12, 1967.

Miller, E. K., Electromagnetic wave scattering from a cylinder in a warm plasma, Proc. URSI Meeting, Ottawa, 1967.

Miller, E. K., Surface current excitation on an inhomogeneously sheathed plasma-immersed cylinder by electromagnetic and electrokinetic waves, Can. J. Physics, 45, pp 1925-1945, 1967.

Miller, E. K., The admittance of an infinite cylindrical antenna in a lossy compressible anisotropic plasma, Can. J. Physics, Vol. 46, pp 2846-2849, December 15, 1968.

Miller, E. K., Admittance of an inhomogeneously sheathed infinite cylindrical antenna immersed in an isotropic, compressible plasma, Trans. IEEE-PGAP, AP-16, No. 4, pp 501-2, 1968.

Miller, E. K., The admittance of the infinite cylindrical antenna immersed in a lossy, compressible plasma, Trans. IEEE-PGAP, AP 16, No. 1, pp 111-117, 1968.

Miller, E. K., An approximate formula for the admittance of a long, thin antenna, Trans. IEEE-PGAP, AP 16, No. 1, pp 127-128, 1968.

Miller, E. K., and H. F. Schulte, On ionospheric composition measurements with an rf impedance probe, Plan. Sp. Sci. 17 pp 1641-56, 1961

Consideration is given to extending various methods used for determining electron number density in the ionosphere to ion composition measurements. A technique involving the impedance of an antenna operated in a frequency range on the order of the ion impedance results for some idealized combinations of ions as well as typical ion mixtures encountered in the ionosphere illustrate application of the technique. The advantages and limitations of the impedance probe are discussed.

Technique Manual

Jones, L. M. (ed) Falling Sphere Method for Upper-Air Density, Temperature and Wind, COSPAR Technique Manual Series, COSPAR Secretariat, Paris, 124 pp, 1967.

Contractor Report

Peterson, J. W. and K. D. McWatters, The Measurement of Upper Air Density and Temperature by Two Radar-Tracked Falling Spheres, NASA CR-29, Wash., 1964.

University of Michigan Scientific Reports (routine status reports excluded)

Schaefer, E. J., and J. Brown, Additional Rocket-Borne Mass Spectrometer Measurements of the Dissociation of Oxygen, 05627-1-S, January 1964.

Schaefer, E. J., and M. H. Nichols, Upper Air Neutral Composition Measurements by Mass Spectrometer, 05627-2-S, January 1964.

Schaefer, E. J., Neutral Composition, 05627-3-S, February 1966.

Miller, E. K., Excitation of Surface Currents on a Plasma-Immersed Cylinder by Electromagnetic and Electrokinetic Waves, 05627-4-S, September 1966.

Miller, E. K., Surface Current Excitation on an Inhomogeneously-Sheathed Plasma Immersed Cylinder by Electromagnetic and Electrokinetic Waves, 05627-5-S, December 1966.

Miller, E. K., The Scattering of Electromagnetic Waves from a Plasma-Immersed Cylinder, 05627-6-S, December 1966.

Ghosh, S. N., Effect of Motion on the Altitude Distribution of Atmospheric Density, 05627-7-S, March 1967.

Ghosh, S. N., Distributions and Lifetimes of N and NO Between 100 and 280 Km, 05627-8-S, March 1967.

Ghosh, S. N., Ionospheric Characteristics from Altitude Variations of Positive Ion Densities, 05627-9-S, March 1967.

Miller, E. K., The Admittance of the Infinite Cylindrical Antenna in a Lossy, Isotropic, Compressible Plasma, 05627-10-S, March 1967.

Miller, E. K., Admittance of the Infinite Cylindrical Antenna in a Lossy Plasma, II. The Incompressible, Magentoplasma, 05627-11-S, May 1967.

Jones, L. M., and J. W. Peterson, Falling Sphere Measurements, 30 to 120 Km, 05627-12-S, June 1967.

Miller, E. K., Admittance of the Infinite Cylindrical Antenna in a Lossy Plasma, III. The Compressible, Magentoplasma, 05627-13-S, October 1967.

Miller, E. K., The Current and Near-Fields of an Infinite Cylindrical Antenna Immersed in a Lossy Plasma Medium, 05627-14-S, December 1967.

Ghosh, S. N., and Ved Mitra, Altitude Distribution, Origin and Flux of Sodium in the Atmosphere, 05627-15-S, March 1968.

Ghosh, S. N., Ionospheric Characteristics from Altitude Variations of positive Ion Densities at Night, 05627-16-S, March 1968.

Ghosh, S. N., and S. K. Gupta, Altitude Distributions of and Radiations from Certain Metastable Constituents, 05627-17-S, March 1968.

Ghosh, S. N., On Solar X-Ray and Radio Emissions from the Sun, 05627-19-S, March 1968.

Miller, E. K. and H. F. Schulte, Jr., Antenna Admittance in an Ionospheric-Type Plasma, 05627-18-S, April 1968.

Miller, E. K. and H. F. Schulte, Jr., Ionospheric Composition Measurements with an R. F. Impedance Probe, 05627-20-S, May 1968.

Miscellaneous The following publications resulted from research supported in the beginning phase by Contract NASr - 54(05).

Jones, L. M., P. B. Hays and H F. Schulte, A Laboratory and Design Study of the Experiments for a Small Aeronomy Satellite, U. of Michigan Report 08235-1-F, 1968.

Roble, R. G., A Theoretical and Experimental Study of the Stable Mid-Latitude Red Arc (SAR-arc) Univ. of Michigan PhD dissertation, 1969.

The stable mid-latitude red arc (SAR-arc) is theoretically and experimentally examined in order to determine the nature of the arc and its role as a neutral gas heat source in the upper atmosphere during geomagnetic storms.

The SAR-arc is considered to be excited by energy flowing from the magneotsphere down along the geomagnetic field lines into the ionosphere. The energy heats the ambient F-region electrons which in turn excite the ^1D state of atomic oxygen by electron impact and gives rise to the 6300 Å emission characteristic of the SAR-arc. The electron heat conduction equation in the F-region of the ionosphere is solved for various heat flows from the magnetosphere in order to determine the atmospheric and ionospheric conditions and energy requirements for red arc formation. The electron temperature, ion temperature, 6300 Å emission rate, and neutral heating height profiles are determined and related to SAR-arc intensity. A two-dimensional model of the SAR-arc is constructed and the neutral heating

height profiles are determined and related to SAR-arc intensity. A two-dimensional model of the SAR-arc is constructed and the neutral heating rates for this model are used to calculate the neutral temperature increase and the atmospheric winds generated by the arc. The results indicate that a large thermal cell develops within the arc region and the peak neutral gas temperature increase within the arc is less than 70°K for a 10 kilorayleigh SAR-arc. The calculated circulation pattern generated by the SAR-arc is shown to produce certain atmospheric and ionospheric effects which are found to agree well with direct measurements made on satellites.

Two optical instruments were constructed to study the SAR-arc and the normal nightglow. The first instrument, a 6" diameter Fabry-Perot interferometer was designed to measure the 6300Å doppler temperature of atomic oxygen. The second instrument is an interference filter photometer which alternately positions 6 interference filters over a telescope and measures the intensity of various emission lines in the night sky. The theory, design, construction, performance tests, and data reduction procedure for both instruments are presented.

The observational results of the SAR-arcs of October 30/31 and October 31/November 1, 1968 are presented. The structure, intensity, and position of the SAR-arc were determined from photometer scan measurements which show that the arc was stable, persisted for more than 12 hours, moved southward during the night, and extended across the eastern part of the United States slightly tilted to lines of constant magnetic L-shells. The results of the doppler temperature measurements made by the Fabry Perot interferometer show no measurable neutral gas temperature increase within the arc in agreement with the theory developed.

The satellite observations on the September 28/29, 1967 SAR-arc are used to theoretically calculate the structure of the arc. The calculated height of the peak emission, the total intensity, and the cross sectional structure of the arc are in agreement with the ground based observational data.

Hays, P. B. and J. J. Olivero, Carbon dioxide and monoxide above the troposphere, submitted to Planet. and Sp. Sci., 1970.

The dependence of the atmospheric distributions of CO_2 and CO upon the combined effects of photochemical production and loss, and diffusion is examined. It is found that, for CO_2, major deviations from complete mixing are possible in both the mesosphere and thermosphere. Further, sufficient quantities of CO may be maintained, as a product of CO_2 photodissociation, to be aeronomically significant.

Acknowledgement

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Submitted for the program

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